NASA Glenn Research Center

Reduced-Noise Gas Flow Design Guide

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Also, thanks are due to those who have worked and are working at NASA Glenn Research Center in the field of aircraft noise control and reduction. They have created an impressive array of noise control concepts and technology, some of which have been made use of in this Guide.

Gratitude is expressed to many persons in the noise control field who assisted in locating and evaluating references and effective analyses, and participated in valuable discussions that helped shape this Guide.

Finally, the author wishes to acknowledge the efforts of Beth A. Cooper, Acoustical Engineer and Manager of Noise Programs at Glenn Research Center, for coordination, advice and review of this material. Her vision and leadership in hearing conservation have built a lasting foundation for a quieter future at Glenn Research Center.

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1. INTRODUCTION

This "Reduced-Noise Gas Flow Design Guide" (*Design Guide*) is intended as a tool for designers and engineers to facilitate design of gas flow equipment to meet NASA Glenn Research Center (GRC) Hearing Conservation requirements. It provides design guidance and noise emission estimates for native-design gas flow systems. Noise emission estimates are also provided for some mechanical equipment that might be purchased from a vendor[i], but which strongly influence the noise emission of a gas flow system.

This *Design Guide* consists of two parts: the written Manual and a Microsoft Excel® Workbook which implements the noise emission estimates.

This *Design Guide* is to be used in conjunction with the NASA GRC *"Guide for Specifying Equipment Noise Emission Levels"* (*Specifications Guide*)[1], which yields noise emission targets for equipment under particular operational and siting conditions. Although the *Specifications Guide* is directed primarily towards specifying noise emission limits for equipment purchased from vendors, it is used here to provide guidance for native-design gas flow equipment.

The Guide is also to be used in conjunction with the NASA GRC Safety Manual, the Environmental Programs Manual and other applicable regulations.

1.1. Scope

1.1.1. Included in Scope

The Scope of the *Design Guide* includes gas-flow noise that originates in turbulent flow processes within the gas itself and then radiates from piping or vessel walls and from atmospheric vents and other openings. The following gas-flow processes are addressed in the *Design Guide*:

- **Vents to atmosphere**: Gas and steam discharge vents, ambient air intake vents, inlet debris screens,
- **Gas-moving equipment**: compressors, exhausters, fans and blowers,
- **Turbomachinery**: Inlet fan and compressor, combustor core, turbine, exhaust jet mixing and exhaust jet shock cells,
- **Flow noise:** from pipe walls and at fittings,
- **Control valves**
- **Flow measurement devices**: orifices and venturis.

[i] Where available, manufacturers' noise emission or noise isolation data is preferred to estimates computed according to this Guide, although the latter may be used as a "reality check" on the former.

The *Design Guide* also addresses noise control performance of elements typically associated with gas flow systems:

- **Walls**: of pipe, duct and vessels
- **Silencers:** vent silencers and in-line silencers,
- **Acoustical Lagging**

1.1.2. Excluded from Scope

The *Design Guide* relates to Hearing Conservation goals in an industrial environment. Personal comfort issues (including speech intelligibility) related to buildings and office environments are not covered because of their differing requirements[ii].

Although a building HVAC system bears a strong resemblance to the gas flow systems treated in the *Design Guide*, a full treatment of HVAC noise is beyond the scope of this document. For engineering information on these systems, consult Schaffer[2] and ASHRAE[3].

Explicitly excluded from the Scope are mechanical or electrical equipment items (e.g., electric motors, pumps, gears) that do not participate directly in the gas flow. Vendors typically supply such devices. Noise emission limits should be specified according to the *Specifications Guide*[1].

The distribution of sound in rooms, the cumulative effect of multiple noise sources and the benefit of sound absorbing materials are handled in a general way in the *Design Guide*. A detailed study of these subjects is beyond the scope of this document. For more guidance in this area, refer to a good noise control engineering text such as Beranek[4], Bies and Hansen[5], Beranek and Vér[6], or NASA[7].

1.2. Relationship of *Design Guide* to *Specifications Guide*

This *Design Guide* and *Specifications Guide* complement one another. The *Design Guide* provides guidance for noise estimation and reduced-noise design. The *Specifications Guide* was developed under a separate contract to define maximum

[ii] Note that levels meeting hearing conservation goals are not necessarily "quiet"; e.g., they do not correspond to a comfortable, office-like environment. In addition, other more stringent noise emission requirements may apply as a result of safety and communications issues.

permissible sound power level (PWL) and/or Sound Level (MPSL) that meet NASA Glenn Hearing Conservation Goals, and to create a concise specification for purchased equipment that maximizes the likelihood of meeting the specified criterion.

The *Specifications Guide* provides noise emission criteria for individual gas flow system components. Special noise transmission problems arise however because of the interconnected nature of these systems. For example, noise generated by a compressor (provided by Vendor A) may exceed the *Specifications Guide* criterion for noise radiating from piping (provided by Vendor B) at some remote location. While the *Specifications Guide* criterion is still valid, the specification of noise emission becomes more complex in such a case.

The *Specifications Guide* also does not provide guidance for NASA Glenn designers and engineers who seek to design gas-flow system equipment to meet the specified limits.

This *Design Guide* specifically addresses estimation of noise emission for individual components as well as complete gas flow systems for comparison with criteria developed under the *Specifications Guide*.

1.3. Technical Approach of *Design Guide*

This *Design Guide* proceeds from the premise that reduced noise emission can be designed into a system as one of many important performance parameters, and addresses the need for a comprehensive set of design tools related to noise emission.

This *Design Guide* also expresses a strong preference for noise control at the source through good design practice rather than using noise control enclosures, barriers and other noise control elements that can interfere with operational and maintenance goals and space limitations.

Methods are provided for estimating and reducing noise emission at an early design stage to facilitate acceptable noise emission. When it appears that desired noise emission levels cannot be attained, the noise emission estimates facilitate the specification, design and selection of noise control elements provided by vendors. In such cases, more detailed guidance is also available from the Noise Exposure Management Program (NEMP, extension 3-3950).

1.4. Intended Audience

The intended audience for the Guide is designers and engineers with a high degree of technical skill. The user need not have formal training in acoustics, but some degree of familiarity with acoustical concepts such as frequency, sound pressure level, octave- and A-weighted filtering, etc. is presumed. A good overview of the subject matter is available in the NASA "Handbook for Industrial Noise Control"[7]. Engineering texts include Beranek[4], Bies and Hansen[5], and Beranek and Vér[6]. An audio-CD has also been produced for NASA GRC that provides demonstrations of acoustic concepts, as well as auditory and hearing conservation effects[8].

Noise estimation equations provided are in algebraic closed form and do not rely on empirical factors that would have to be derived from acoustical experiments. Parameters of the predictive equations consist of readily available design information, such as mass flow rates, gas properties, pipe diameter and wall thickness, etc. No hand calculations are necessary: the accompanying Workbook (described below) implements the engineering equations described in this text.

Other engineering information is communicated using tables, graphs, diagrams, and sketches. Words defined in the "Definition of Noise Control Terms" (Appendix B, page B-1) are set in italics.

1.5. Feasibility

NASA GRC Hearing Conservation policy requires that equipment noise emissions conform to emission limits derived according to the *Specifications Guide*. Engineering measures to achieve the appropriate levels are often technically feasible but may not be reasonable because of performance, economic or space limitation factors. The Noise Exposure Management Program of the Environmental Management Office should be consulted if the required level of noise control proves to be infeasible in a particular application.

1.6. Support Software

The *Design Guide* is accompanied by a diskette with the following computer software items:

- a Microsoft Excel® workbook (Workbook) entitled "Gas Flow Noise Estimation.xls" that performs noise estimation computations for individual equipment items and a basic gas flow system. The Office 97 version of Excel® is required to run this Workbook.
- a Microsoft Word® file entitled "Lagging Specifications.doc" containing a basic acoustical lagging specification identical to that provided in Section 8.2.1 (page 8-4). This document is the same as provided with the *Specifications Guide*, and is in Microsoft Office 97® format.
- a Microsoft Excel® workbook entitled MNEW-1.XLS (for Machinery Noise Emission Worksheet) that assists in the determination of Maximum

Permissible Sound Levels for equipment. This workbook is the same as provided with the *Specifications Guide*, and runs in Excel 5.0® or later.

- a Microsoft Word® file entitled "Speclang.doc" that incorporates specification language recommended in the *Specifications Guide*. This file is the same as provided with the *Specifications Guide* and is in Word® 6.0 format.

The files are compressed onto a single diskette in the form of a self-extracting executable file "Design Guide.EXE". In order to make the files usable, they must first be extracted. The file "Design Guide.EXE" should be copied to a convenient subdirectory on a hard disk drive. Run the application (by double-clicking on it's icon in Windows 95®) or by using the "Run" command from the Start Button on the Task Bar. The files will be extracted into the subdirectory you specify and are then ready for use. Please note that the files are too large to be extracted to the diskette itself.

1.7. Disclaimer

Noise control design of gas flow systems can be an extremely complex engineering task. The *Design Guide* is not intended as a substitute for the services of an experienced noise control professional.

The noise emission estimates reported herein are drawn from the open noise control literature and are believed to be appropriate for the types of gas flow systems present at NASA Glenn Research Center. It should be noted however that they incorporate a number of assumptions that may not apply in particular cases. Therefore, Nelson Acoustical Engineering, Inc. makes no warranty concerning the applicability or accuracy of noise emission estimates produced in accordance with this *Design Guide*.

Finally, the *Design Guide* makes no effort to be original in its methods. Most of the methods recommended in the *Design Guide* are the well-accepted work of others in the noise control field. The methods were selected for appropriate balance between simplicity and accuracy. Every effort has been made to give proper attribution to those whose work has become a part of the Guide. Apologies are offered to any who feel they have been overlooked.

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[1] David A. Nelson, *Guide to Specifying Equipment Noise Emission Levels,* Hoover & Keith, Inc. under contract to NASA Glenn Research Center, 1996. This Guide may be obtained from the Noise Exposure Management Program ((216) 433-3950, or via http://www-osma.grc.nasa.gov/oep/nmtpages/oep_nt.htm)

[2] Mark E. Schaffer, *A Practical Guide to Noise and Vibration Control for HVAC Systems*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1991

[3] *1991 Applications Handbook,* Chapter 42: Sound and Vibration Control, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, 1991

[4] Leo L. Beranek, Ed., *Noise and Vibration Control, Revised Edition*, Institute of Noise Control Engineering, Poughkeepsie, NY, 1988

[5] David A. Bies and Colin H. Hansen, , *Engineering Noise Control, Theory and Practice, Second Edition*, E&FN Spon, London, 1996

[6] Leo L. Beranek and István L. Vér, *Noise and Vibration Control Engineering, Principles and Applications*, John Wiley & Sons, Inc., New York, 1992

[7] The Bionetics Corporation, *Handbook for Industrial Noise Control,* NASA SP-5108, 1981

[8] David A. Nelson and J. Ashton Taylor, *Auditory Demonstrations in Acoustics and Hearing Conservation*, Hoover & Keith Inc. under contract to NASA Glenn Research Center, 1997

2. USE OF *DESIGN GUIDE*

The goal of this *Design Guide* is to use standard gas-flow system design parameters to obtain noise emission estimates. These noise emission estimates are compared to criteria recommended by the *Specifications Guide* in order to determine if a design is sufficient or if further noise reduction efforts are warranted.

Some of the components covered by the *Design Guide* are mechanical equipment items that might be purchased from vendors. In this case, the noise emission estimates are particularly helpful for old equipment for which acoustical data is no longer available, for new equipment for which data has not yet been developed or not yet obtained from the manufacturer, or simply to provide a check on manufacturers' estimates.

Before beginning to use the *Design Guide* in support of a particular project, take time to consider which equipment is likely to produce significant amounts of noise. Obvious candidates include equipment with a history of or reputation for noisy operation, and large equipment items about whose noise emission characteristics little is known. Consider also the variety of paths that sound might take within the system: if there's a way for the sound to escape into the environment, expect that it will do so at the least favorable location.

Next, use the *Specifications Guide* to develop noise emission criteria for each individual system component. *Specifications Guide* criteria are advantageous because they are flexible enough to allow for a variety of siting and operational considerations. They also provide for a consistent set of criteria amongst equipment designed at NASA and equipment supplied by vendors. A system made up of components specified according to the *Specifications Guide* is expected to be compatible with NASA GRC hearing conservation goals.

Locate the sections of this *Design Guide* Manual that relate to each piece of equipment under consideration. Review the information describing how noise is generated in each case. Awareness of the noise generation mechanisms will help the designer avoid design practices that may be inherently noisy.

Guidelines are provided for reduced-noise design. Consider how these guidelines can be incorporated along with other design considerations. While in some cases these guidelines will complicate the already difficult task of balancing competing design requirements, realize that in many cases implementation of noise control design can actually lead to improved system performance through reduction of turbulence levels, vibration and pressure drop.

Once the design is underway and sufficient information is available, use the Excel® "Gas Flow Noise Esimation.XLS" workbook (Workbook) to estimate the noise emission for each component. For those who are interested and for those who have a unique application that departs from the applications used here, equations describing the noise emission estimates are provided.

Required input parameters are tabulated in the *Design Guide* Manual for each equipment type. The input parameters consist of design parameters commonly available in early project design phases, and do not require performance of any acoustical tests. Note that the Calculator spreadsheet (Section 2.4.4, page 2-11) within the Workbook can be used to estimate unknown required gas flow parameters from known ones.

Compare the estimated noise emission levels to the criterion levels recommended by the *Specifications Guide*. Identify frequency ranges that must be addressed first.

The design of a component may need to be improved iteratively. In some cases it may not be possible to achieve acceptable levels without the assistance of noise control equipment such as enclosures, silencers, and lagging. The noise emission estimates should be helpful in the proper selection of such equipment.

At any point along the way, the results of noise estimates on individual components may be incorporated into a System Analysis supported in the Workbook. Two spreadsheets within the Workbook perform all of the tedious accounting work necessary to estimate the system-related effects.

2.1. Equipment Covered

The gas flow system components listed below are covered by the *Design Guide* Manual and Workbook. They are organized here by principle mechanism of noise generation.

- Free Jets (Chapter 1):

  High velocity gas or steam discharge to atmosphere

- Constrained Jets (Chapter 5):

  Control valves
  Measurement orifices and venturis
  High velocity vacuum intake

- Gas-Moving Equipment and Flow Interaction with Structures (Chapter 6):

  Compressors and exhausters
  Fans and blowers
  Flow noise from pipe walls and fittings
  Air inlet debris screen

- Turbomachinery (Chapter 7):

  Inlet fan and compressor
  Combustor
  Turbine
  Jet exhaust (mixing and shock-associated noise)

- Noise Controlling Elements (Chapter 8):

  Pipe, duct, vessel and tank walls
  Silencers
  Lagging
  Reflection of noise at an open pipe end

2.2. *Specifications Guide* Criteria

The *Specifications Guide* requires that equipment noise levels not exceed a maximum permissible sound level (MPSL) when measured under appropriate load 1 meter from the equipment. For equipment sited outdoors, limiting octave band sound power levels are also given.

A baseline noise emission criterion (in A-weighted dB re 20 Pa) is assigned to each Equipment Group defined in the *Specifications Guide*. The MPSL may differ from the baseline noise emission criterion, depending on seven adjustments that take into account various siting and operational characteristics. The net adjustment may be between −10 dB(A) and + 25 dB(A). Baseline noise emission criteria for the equipment types covered in this *Design Guide* are listed below according to Group numbers assigned in the *Specifications Guide*:

- **Group 1: Heavy Machinery**

  Control valves
  Measurement venturis and orifices
  Compressors and exhausters
  Blowers and fans

- **Group 2: Vents to Atmosphere**

  High velocity discharge of gas or steam to atmosphere
  High velocity intake of air from atmosphere
  Air inlet debris screen

- **Group 3: Piping and Ductwork**

  Flow noise generated at pipe walls and fittings

- **Group 4: Light Machinery**

  Building ventilation fans or blowers

- **Group 5: Transformers** (Not applicable to this *Design Guide*)

2.3. Equipment Types Covered

Equipment types covered by the *Design Guide* are arranged into four general classes depending on the primary method of noise generation. One Section is devoted to each:

- Free Jets (Chapter 1)
- Constrained Jets (Chapter 5)
- Gas-Moving Equipment and Flow Interaction with Structures (Chapter 6)
- Turbomachinery (Chapter 7)

Section 7 deals with turbomachinery noise from an industrial noise control standpoint. NASA GRC has produced a large body of research on aircraft engine noise and noise control over the years. Some of that research has been incorporated into the *Design Guide*. The equations are used in simplified form to predict gross behavior.

Section 8 addresses elements that reduce or constrain noise, including pipe walls, silencers, acoustical lagging, and rooms.

For each case, four types of information are provided:

- The physical mechanisms of noise production, noise reduction and noise transmission explained for each class of equipment.
- Design guidelines for reduced-noise equipment operation.
- Design parameters required for noise emission estimation using the Workbook and notes on their use are enclosed in a box.
- Predictive equations for noise emission, based on readily available design information.

2.4. Workbook

A Microsoft Excel® workbook (Workbook) has been developed to accompany the *Design Guide*. The Workbook comprises a series of spreadsheets that perform the noise emission estimation and noise control calculations. One spreadsheet ("System Input-Output") integrates the results of individual computations into a basic model system to evaluate the effects of noise traveling throughout the system.

The workbook spreadsheets and most cells are protected and the file is saved in read-only format to prevent accidental erasure or modification. To modify the workbook or access its contents, it may be unlocked using the sequence Tools / Protection / Unprotect Sheet. No password is required.

Each spreadsheet presents a computation form that guides the user through entering the relevant input parameters. Data entry is made in unlocked cells denoted by white background, bold type and a black outline. Units for data entry are selectable by the User by means of drop-down lists. Units may be mixed without restriction.

A blue background denotes spreadsheet outputs. Units for outputs are selectable by the User by means of drop-down lists. Units may be mixed without restriction.

Noise emission estimates are compared directly with a Maximum Permissible Sound Level (MPSL) value entered by the User and with the sound power level limits for outdoor equipment. To assist the User in determining which octave bands must be reduced to achieve the criterion, octave bands that individually contain enough energy to exceed the criterion are denoted by a bright red background and bold, white characters. An orange background with bold, black characters denotes octave bands that individually are within 5 dB of the criterion. If the criterion is exceeded, additional noise control must begin in the bands with red cells and may be required in the bands with orange cells as well.

For comparison with the octave band sound power level criterion, a bright red background and bold, white characters denote octave bands that exceed the criterion. An orange background with bold, black characters denotes octave bands that individually are within 5 dB of the criterion. Note that these color codes are provided for information only: when the criterion is exceeded, additional noise control must begin in the bands with red cells and may be required in the bands with orange cells as well.

Octave-band values intended for use as inputs to the System Input-Output spreadsheet are highlighted with a salmon-colored background. A light yellow background denotes tabular information. Octave-band sound power level criteria are displayed with a gray background.

Examples of each of these formats along with other helpful information can be found in the "Read Me" spreadsheet of the Workbook.

2.4.1. Single Component Design

When designing a single component, each Spreadsheet may be used to provide a "stand-alone" estimate of the radiated and in-duct sound power level, as well as the Sound Pressure Level at a location of the User's choice. Octave band and A-weighted output values are provided.

Some noise control devices have noise control equipment that is an integral part of the device, e.g., in-line silencers for valves. In such cases, a calculation of their noise control benefit takes place directly on the spreadsheet for that device.

Spreadsheets are provided for the following equipment types:

- Intake Vents
- Venturis and Orifices
- Inlet Debris Screen
- Control Valves
- Compressors and Exhausters
- Blowers and Fans
- Jet Engine Fan and Inlet Compressor
- Jet Engine Combustor
- Jet Engine Turbine
- Jet Exhaust Mixing and Shock-Associated Noise
- Gas Vents and Reliefs
- Steam Vents and Reliefs
- Flow Noise in Pipes
- Preliminary Silencer Selection
- Pipe and Duct Wall Transmission Loss
- Reflection Loss at Pipe End with Flow
- Gas Flow Calculator

2.4.2. System Input-Output Spreadsheet

The System Input-Output spreadsheet combines the results of noise emission and noise control estimates for individual components into a simplified gas flow system analysis.

The gas flow system is conceived as comprising Intake, Equipment, and Discharge. Either the Intake or Discharge may independently be assigned "Open" or "Closed Loop" status to indicate whether the Intake or Discharge is open to the environment. Intake and Discharge openings, when present, are assumed to be located Outdoors.

The Equipment is conceived as being located together in a well defined area. That are may be defined as being enclosed ("Indoors") or unenclosed ("Outdoors"). When enclosed, the Transmission Loss of the building is assumed to be sufficient to eliminate the Equipment and Indoor Piping noise from consideration at outdoor locations.

Two user-definable observation positions are defined, one entitled Outdoor Observation Position and the other entitled Indoor Observation Position. When the Equipment is designated as "Indoors", sound pressure level estimates for the Indoor and Outdoor Observation Positions address Indoor and Outdoor components respectively. When the Equipment is designated as "Outdoors", the Indoor Observation Position noise estimates continue to address the Equipment and Indoor Piping only. In this case however the estimates for the Outdoor Observation Position address all Equipment.

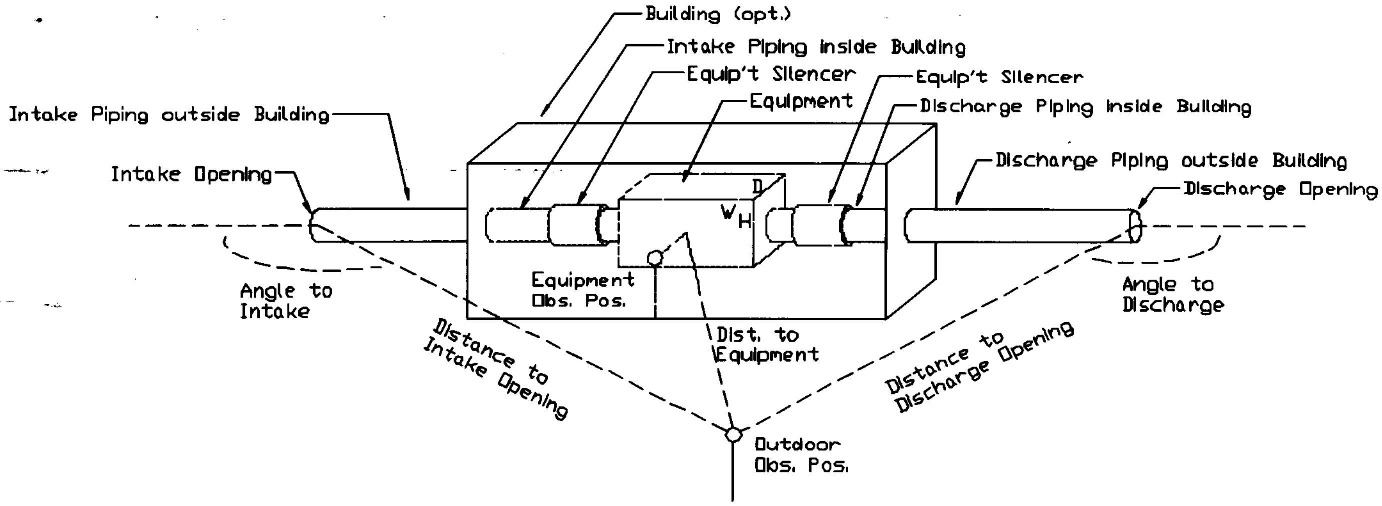

Figure 1: System Diagram

The analysis permits silencers to be introduced at both the Intake and Discharge of the Equipment package, and treats the silencers as if there was no intervening piping or ductwork. Thus, all Indoor and Outdoor Piping and Intake and Discharge Openings benefit from their presence.

Silencers may also be inserted at both the Intake and Discharge openings.

Control valves may be directly associated with the Intake or Discharge openings as well.

Acoustical Lagging may be added in three thicknesses (2, 4, and 6 inches) independently to Outdoor Intake Piping, Indoor Intake Piping, Indoor Discharge Piping and Outdoor Discharge Piping.

Data is entered into the System Analysis using the System Input-Output Spreadsheet, which is divided into four sections:

- Section 1 reproduces Figure 1 above for reference.
- Section 2 collects information on the System Geometry, including
  - Piping Diameter, Intake and Discharge
  - Length of Piping Indoors, Length of Piping Outdoors, for Intake and Discharge
  - Open or Closed state of Intake or Discharge
  - Observation Distance
  - Observation Angle relative to Intake and Discharge Opening

- Equipment Location (Indoors or Outdoors)
- If Indoors, Building Length, Height, Width and Percent Surface Area Coverage with Sound Absorbing Materials.
- Equipment Dimensions (Length, Width, Depth)
- Distance from Equipment to Indoor and Outdoor Observation Positions

➢ Section 3 collects information regarding Criteria as developed from the *Specifications Guide* and as further defined by the User.

- MPSL Critera for Intake and Discharge Openings
- MPSL Critera for Indoor Intake and Discharge Piping
- MPSL Critera for Outdoor Intake and Discharge Piping
- Desired A-weighted Sound Pressure Level at Outdoor Observation Position
- Desired A-weighted Sound Pressure Level at Indoor Observation Position
- In-Duct Sound Power Levels re Structural Fatigue Criterion for Intake and Discharge Piping

A summary of the program output is also given in Section 3.

- Estimated A-weighted Sound Pressure Level at 1 meter and A-weighted Sound Power Level from Intake and Discharge Openings, color coded as described in *Design Guide* Section 2.4.
- Estimated A-weighted Sound Pressure Level at 1 meter and A-weighted Sound Power Level from Indoor Intake and Discharge Piping, color coded as described in *Design Guide* Section 2.4.
- Estimated A-weighted Sound Pressure Level at 1 meter and A-weighted Sound Power Level from Outdoor Intake and Discharge Piping, color coded as described in *Design Guide* Section 2.4.

➢ Data obtained from individual component analysis spreadsheets is entered into Section 4. Unneeded or unused input cells should be blanked or filled with zeroes. Section 4.a covers the Intake components:

- Intake Vent Sound Power Levels, Unsilenced
- Intake Control Valve Sound Power Levels, Unsilenced
- Intake Silencer Insertion Loss
- Intake Silencer Self-Noise
- Reflection Loss at Intake Opening
- Inlet Debris Screen Sound Power Level
- Intake Piping Transmission Loss
- Intake Piping Flow Noise, Unlagged, per 10 ft. Length
- Outdoor Intake Pipe Lagging Thickness (inches)

Section 4.b covers the Discharge components:

- Discharge Vent Sound Power Levels, Unsilenced
- Discharge Control Valve Sound Power Levels, Unsilenced
- Discharge Silencer Insertion Loss
- Discharge Silencer Self-Noise
- Reflection Loss at Discharge Opening
- Discharge Piping Transmission Loss
- Discharge Flow Noise, Unlagged, per 10 ft. Length
- Outdoor Discharge Pipe Lagging Thickness (inches)

Section 4.c covers Indoor Silencers and Pipe Lagging:

- Intake Silencer Insertion Loss
- Intake Silencer Self-Noise
- Indoor Intake Pipe Lagging Thickness (inches)
- Discharge Silencer Insertion Loss
- Discharge Silencer Self-Noise
- Outdoor Intake Pipe Lagging Thickness (inches)

Section 4.d incorporates the results of Component noise emission estimates for each of up to six equipment components:

- In-Duct Sound Power Level traveling in Upstream Direction
- In-Duct Sound Power Level traveling in Downstream Direction
- In-Duct Sound Power Level radiating from Casing, Unlagged
- Casing Lagging Thickness (inches)

2.4.3. System Calculations Spreadsheet

The System Calculations Spreadsheet exposes the details of the calculations for inspection by the User. It is most useful when trying to answer questions such as:

- ➢ What octave bands require noise control in order to reduce the estimated level?
- ➢ What source of noise dominates in a particular section of the System?
- ➢ What are the effects of piping length on noise radiation?

Section 1 displays the System Diagram and summarizes the System Geometry information given on the System Input-Output Spreadsheet.

Section 2 summarizes the Sound Pressure Level and Sound Power Level computations relating to outdoor portions of the Intake system.

- Section 2.a: Estimated Intake Opening contribution at Outdoor Observation Position, and at 1 meter from Opening with comparison to criteria
- Section 2.b: Estimated Intake Piping contribution at Outdoor Observation Position, and at 1 meter from Piping with comparison to criteria
- Section 2.c: Estimated Summary of Noise Radiated to Outdoor Observation Position from Outdoor Intake Opening and Piping with comparison to criteria.

Section 3 reproduces the Equipment Intake Silencer Insertion Loss and Self-Noise input data.

Section 4 collects the information regarding noise emission from Equipment components:

- Section 4.a: Totals the estimated Equipment sound power level traveling upstream and comparison with structural fatigue criterion
- Section 4.b: Totals the estimated Equipment sound power level traveling downstream and comparison with structural fatigue criterion.
- Section 4.c: Totals the estimated Equipment sound power level radiated from unlagged Equipment casings, the selected lagging treatments, and the estimated sound power level radiated from lagged Equipment casings
- Section 4.d: Estimated Intake Piping contribution at Indoor Observation Position, and at 1 meter from Piping with comparison to MPSL
- Section 4.d: Estimated Discharge Piping contribution at Indoor Observation Position, and at 1 meter from Piping with comparison to MPSL
- Section 4.d: Total of Equipment Casing, Intake and Discharge Piping Noise, Indoors, with comparison to A-weighted Sound Pressure Level Target
- Section 4.d: Total of Equipment Casing, Intake and Discharge Piping Noise, if Outdoors, with comparison to A-weighted Sound Pressure Level Target

Section 5 reproduces the Equipment Intake Silencer Insertion Loss and Self-Noise input data.

Section 6 summarizes the Sound Pressure Level and Sound Power Level computations relating to outdoor portions of the Discharge system.

- Section 6.a: Estimated Discharge Opening contribution at Outdoor Observation Position, and at 1 meter from Opening with comparison to criteria
- Section 6.b: Estimated Discharge Piping contribution at Outdoor Observation Position, and at 1 meter from Piping with comparison to criteria
- Section 6.c: Estimated Discharge Summary of Noise Radiated to Outdoor Observation Position from Outdoor Intake Opening and Piping, with comparison to criteria

Section 7 documents the overall results for the Outdoor Observation Position including outdoor components associated with both the Intake and Discharge systems.

2.4.4. Gas Flow Calculator

A spreadsheet is included that serves as a general calculator useful for gas flows and noise emission. It facilitates conversion of known parameters into required inputs when these are unknown. The spreadsheet includes calculators for the following:

- *Ideal Gas*: solve for Pressure, Temperature or Density given the other two.
- *Isentropic Expansion and Contraction*: solve for Temperature, Density, Velocity and Sonic Velocity of an expanded or contracted gas from the pressures before and after expansion or contraction.
- *Velocity, Mass Flow and Volume Flow Conversions:* Find any two of the three given the other and pipe diameter.
- *Sonic Velocity and Mach Number:* from Gas Velocity and Temperature
- *Units Converter:* Convert values from one system of units to another
- *Decibel Mathematics:* addition and subtraction of decibel spectra, and three types of wave divergence computation.